

*REINFORCER EFFECTIVENESS AS A FUNCTION OF
REINFORCER RATE AND MAGNITUDE: A
COMPARISON OF CONCURRENT PERFORMANCES¹*

J. W. SCHNEIDER

MCMASTER UNIVERSITY

Pigeons' pecks on each of two concurrently available response keys were reinforced under a variable-interval schedule that sometimes allotted food-pellet deliveries to one key and sometimes to the other. The keys differed in the number of reinforcements assigned to each and in the number of pellets delivered during each reinforcement. When the total quantity of food associated with each key during a session was constant, the proportion of responses to a key depended on the particular combinations of reinforcer rate and reinforcer magnitude scheduled on each key. A given quantity of food generated more responding on a key when it was delivered frequently in small amounts than when it was delivered infrequently in large amounts.

A given quantity of reinforcing substance may be dispensed within a specified period of time in frequent small portions or in less frequent large portions. When reinforcement is contingent on a particular response, a greater number of those responses are reinforced in the former case. Fewer responses produce reinforcement in the latter case, but each reinforcer is greater in magnitude. A question of some practical and theoretical importance is whether such differences in the manner in which a quantity of reinforcer is apportioned affect the level of responding that may be maintained by that quantity of reinforcer.

The present experiment investigated this question by comparing the rates of two concurrently maintained responses that differed in locus and in the manner in which their allotted quantities of reinforcer were apportioned in time. On one response key, pigeons' pecks were intermittently reinforced at rate r_1 with reinforcers of magnitude a_1 ; on a second key, pecks were intermittently reinforced at rate r_2 with reinforcers of magnitude a_2 . The particular combinations of rate and magnitude utilized on each key were varied from one experimental condition to the next. In one series of conditions, the total amount of food allotted to each key was one half the total amount delivered during the experimental

sessions. In other series, the proportion of food delivered for pecking one key was one fourth or one eighth of the total amount consumed during the session. With the total amounts of reinforcer associated with each key fixed within each of these series, the values of reinforcer rate and reinforcer magnitude associated with a key were varied inversely. In most conditions, the two keys differed with respect to both reinforcer rate and magnitude.

Many investigators have found that when the reinforcers associated with two concurrent schedules differ only in their rates of occurrence, the proportion of responses under either schedule approximately equals the proportion of food made available under that schedule (e.g., Herrnstein, 1961; Catania, 1963a; Stubbs and Pliskoff, 1969). This relation has come to be known as the "matching law" between relative rate of responding and relative rate of reinforcement (Herrnstein, 1970; Rachlin, 1971). A similar matching relation has been hypothesized to apply when the proportion of food a schedule provides is varied by manipulating the duration (magnitude) of food presentations, rather than the rate at which the food presentations occur (Brownstein, 1971; Rachlin and Baum, 1969; Rachlin, 1971). This relation, if true, would suggest that reinforcer rate and reinforcer magnitude are functionally equivalent, both affecting choice by their influence on the overall proportion of reinforcer a schedule provides.

Experimental evidence for such a matching relation between relative rate of responding

¹This research was conducted under a postdoctoral fellowship in the Department of Psychology, McMaster University. Reprints may be obtained from the author, Department of Psychiatry, McMaster University Medical Centre, Hamilton, Ontario, Canada.

and relative duration reinforcement is scant, however. Catania (1963*b*) reported data in which the relative rates of pigeons' pecks matched the relative duration of reinforcement (access to grain) provided under two equal-valued variable-interval (VI) schedules. Subsequent studies more specifically designed to test the hypothesis of equality between relative rate of responding and relative duration of reinforcement have generally failed to provide firm support for this relation (Walker and Hurwitz, 1971; Walker, Schnelle, and Hurwitz, 1970) or have reported other relations that are clearly incompatible with matching (Fantino, Squires, Delbrück, and Peterson, 1972). One investigator (Todorov, 1973) manipulated both rate and duration of food presentation and found that duration of food presentation had less effect on relative response rate than did rate of food presentation. This result is inconsistent with the hypothesis that rate and duration of reinforcement are functionally equivalent and that relative response rate (choice) may be predicted solely on the basis of the relative total access to reinforcement made available under each schedule.

The present investigation provides further data on the effects of rate and magnitude of reinforcement on concurrent responding. Certain procedural features employed in this experiment provide more control over relative rate of reinforcement and relative magnitude of reinforcement than has been the case in most earlier investigations. Prior studies of the effects of rate or magnitude of reinforcement on concurrent responding have typically employed independent VI schedules on the two keys. A drawback of this arrangement is that the relative rate of reinforcement actually obtained on a key may vary importantly with concurrent performance and may therefore be difficult to control accurately or predetermine. This difficulty was avoided in the present experiment by employing a variation of the usual concurrent procedure: all reinforcements were delivered by a single VI schedule that allotted a specified proportion of reinforcements to each key in a randomized sequence. Results of previous studies using this, or similar variations of the concurrent procedure (Herbert, 1970; Shimp, 1971; Stubbs and Pliskoff, 1969; Walker and Hurwitz, 1971), suggest that performance follows the same re-

lations recognized as governing performance when pairs of independent concurrent schedules are used.

Most studies of concurrent performance that have focussed on magnitude of reinforcement have manipulated duration of access to food rather than the actual amount of food consumed (*e.g.*, Catania, 1963*b*; Fantino *et al.*, 1972; Todorov, 1973). It is not clear, however, whether reinforcer magnitude should most usefully be measured as reinforcer duration or reinforcer quantity. While it may reasonably be assumed in the earlier studies that the quantity of food (usually mixed grain) consumed is approximately proportional to the duration of the reinforcement cycle, deviations from this proportionality may be expected when the reinforcement cycle is very brief or, perhaps, very long. In the present experiment, reinforcement consisted of the delivery of a train of food pellets, a procedure that allowed precise control over the quantity of food ingested during each reinforcement cycle. The duration of a reinforcement cycle was always proportional to the number of pellets delivered.

METHOD

Subjects

Four male Silver King pigeons were maintained at 80 to 85% of their free-feeding weights during the experiment. All had been used earlier in an undergraduate laboratory course and had been trained to key peck under various schedules of positive reinforcement.

Apparatus

A two-key operant chamber for pigeons (Lehigh Valley Electronics Model 1519) was modified to accommodate a Gerbrands pellet dispenser (Model D-1) in place of the original grain hopper. Pellets were dispensed into a recessed receptacle accessible through an opening in the front panel below and midway between the response keys. This receptacle was illuminated during food presentations. The translucent response keys were 16.5 cm (6.5 in.) apart and were operated by pecks of at least 10 g (0.1 N) force. The left key was transilluminated by green light, the right key by red light. A white houselight provided continuous chamber illumination, and white

noise was continuously present to mask external sounds. A one-way mirror mounted in a side wall of the chamber allowed observations of events within the chamber. Electromechanical scheduling and recording equipment was located in an adjoining room.

Procedure

Pecks on the two keys were reinforced under a single VI schedule that allotted successive reinforcements to one key or the other in a predetermined irregular sequence. The sequence was changed every third session. When reinforcement became available on either key, the interval timer stopped and reinforcement remained available until produced by a peck on that key. Reinforcement consisted of the delivery of a train of uniform food pellets. As described below, the number of reinforcements and the number of pellets per reinforcement typically differed on the two keys.

Each experimental session was terminated when 400 pellets had been delivered. For two pigeons, S1 and S2, the 400 pellets were always delivered within sessions of about 64 min duration (60 min keys-on time plus 4 min total reinforcement time). For another pair of pigeons, S3 and S4, the 400 pellets were delivered during the course of 14-min sessions (10 min keys-on time plus 4 min total reinforcement time). Actual session durations typically differed slightly from the scheduled values because pigeons did not always obtain reinforcements as soon as the scheduled intervals elapsed.

Three series of experimental conditions were conducted. In the conditions of Series 1, 300 pellets were delivered on the left key and 100 pellets on the right key during each session. In Series 2, 350 pellets were delivered on the left key and 50 pellets on the right key. During Series 3, 200 pellets were delivered on each key.

The combination of reinforcer rate and reinforcer magnitude employed on each key to deliver the assigned total number of pellets on that key differed from one condition to the next within each series as shown in Table 1, which also presents the schedule values employed. In each condition, the VI schedule consisted of 10 randomly ordered intervals selected according to an equal-probability progression described by Fleshler and Hoffman (1962).

A changeover delay (COD) of 1.5 sec was used throughout the experiment to discourage the development of concurrent superstitions (Catania, 1966). Pecks occurring within the first 1.5 sec after a switch from one key to the other did not produce reinforcement.

During experimental sessions, the left key (green) and the right key (red) were lighted and operative except during reinforcement cycles. A peck earning reinforcement darkened both keylights, illuminated the food cup, and initiated the delivery of a train of food pellets into the cup. Pellets were delivered one at a time at a rate of four per second. The food cup remained illuminated for a duration proportional to the number of pellets delivered (0.6 sec per pellet). This value was selected after preliminary observations indicated that the subjects consumed pellets at rates ranging from approximately 0.45 to 0.55 sec per pellet. Repeated observations during the experiment revealed no instance in which the available pellets were not all consumed within the allotted reinforcement cycle. At the end of a reinforcement cycle the keys were reilluminated and the timing of the next interval began.

The food pellets were 4.0 by 3.3 mm, 45-mg pellets for pigeons supplied by P. J. Noyes Co. The 400 pellets delivered per session maintained each pigeon within its 80 to 85% body weight with few extra feedings in its home cage. Extra feedings consisted of mixed grain. Experimental sessions were conducted daily five or six times per week.

The number of reinforcements and the number of pellets per reinforcement associated with each key under the various conditions are shown in Table 1. Each condition was continued until variations in the proportion of responses to a key during consecutive sessions appeared to exhibit no systematic trend. This required from eight to 15 sessions per condition (Table 1). Conditions are listed in Table 1 in their order of occurrence.

RESULTS

A main concern of the present study was to determine whether the distribution of responses across concurrent alternatives depends only on the total quantity of reinforcing substance delivered by each alternative or whether it depends on the particular combina-

Table 1

Summary of experimental conditions and data. The response rates, changeover rate, and session duration listed in each row are from the session yielding the median value of relative choice among the final three sessions of the condition. Session durations do not include time elapsed during reinforcement cycles.

Series	Condi- tion	Subject	Pellets Per Reinforcement		Number of Reinforcements		VI Value (sec)	Session Duration (min)	Responses Per Minute		Changeovers Per Minute	Sessions
			Left	Right	Left	Right			Left	Right		
1	1	S1	15	5	20	20	90	62.2	69.0	44.6	10.2	15
		S2	15	5	20	20	90	65.2	43.1	22.2	10.0	15
	2	S3	15	5	20	20	15	12.9	62.3	37.2	12.1	15
		S4	15	5	20	20	15	13.0	60.0	37.4	8.8	15
	3	S1	5	5	60	20	45	63.5	79.4	37.9	8.1	8
		S2	5	5	60	20	45	62.8	48.4	18.5	8.5	8
	4	S3	5	5	60	20	7.5	12.2	53.5	25.0	11.5	11
		S4	5	5	60	20	7.5	14.6	66.8	28.3	7.6	11
	5	S1	30	2	10	50	60	61.7	61.2	37.7	10.9	8
		S2	30	2	10	50	60	63.6	32.7	43.0	8.4	8
	6	S3	30	2	10	50	10	11.8	60.9	42.9	16.5	8
		S4	30	2	10	50	10	11.5	37.7	34.4	10.1	8
	7	S1	5	20	60	5	55.4	63.7	85.1	38.5	12.0	9
		S2	5	20	60	5	55.4	66.7	43.8	14.7	8.6	9
	8	S3	5	20	60	5	9.2	12.1	90.6	27.0	12.1	9
		S4	5	20	60	5	9.2	12.4	73.9	26.9	9.6	9
2	1	S1	25	2	14	25	92.4	53.1	92.4	48.9	14.4	8
		S2	25	2	14	25	92.4	57.1	27.3	26.1	8.5	8
	2	S3	25	2	14	25	15.4	12.6	71.9	40.1	16.9	9
		S4	25	2	14	25	15.4	12.7	71.2	39.3	11.5	9
	3	S1	5	25	70	2	50	67.6	102.1	30.3	12.3	10
		S2	5	25	70	2	50	73.1	43.9	6.8	3.8	10
	4	S3	5	25	70	2	8.3	13.0	72.6	12.5	5.2	9
		S4	5	25	70	2	8.3	13.8	95.6	13.6	4.5	9
	5	S1	14	2	25	25	72	63.3	88.6	42.8	11.8	8
		S2	14	2	25	25	72	65.7	36.4	15.3	8.1	8
	6	S3	14	2	25	25	12	12.0	69.6	25.8	12.7	8
		S4	14	2	25	25	12	11.1	99.4	35.5	7.0	8
	7	S1	25	25	14	2	211.8	65.9	96.6	35.1	9.9	8
		S2	25	25	14	2	211.8	58.7	36.6	14.3	7.7	8
	8	S3	25	25	14	2	35.3	10.0	73.3	18.1	7.5	9
		S4	25	25	14	2	35.3	10.9	83.9	27.9	8.8	9

Table 1 continued

Series	Condi- tion	Subject	Pellets Per Reinforcement		Number of Reinforcements		VI Value (sec)	Session Duration (min)	Responses Per Minute		Changeovers Per Minute	Sessions
			Left	Right	Left	Right			Left	Right		
3	1	S1	25	2	8	100	33.3	63.8	62.3	64.6	18.1	9
		S2	25	2	8	100	33.3	69.3	16.0	56.1	15.6	9
	2	S3	25	2	8	100	5.6	14.5	49.1	71.7	16.2	9
		S4	25	2	8	100	5.6	12.5	33.0	103.5	14.8	9
	3	S1	4	20	50	10	60	61.3	76.3	58.1	15.9	8
		S2	4	20	50	10	60	60.2	39.1	23.1	9.2	8
	4	S3	4	20	50	10	10	11.4	66.2	35.8	11.9	8
		S4	4	20	50	10	10	11.8	82.5	44.0	11.0	8
	5	S1	20	4	10	50	60	63.5	59.6	65.3	16.4	8
		S2	20	4	10	50	60	68.5	21.5	51.8	10.0	8
	6	S3	20	4	10	50	10	11.5	71.1	68.1	12.4	9
		S4	20	4	10	50	10	12.8	53.7	64.8	10.6	9
	7	S1	20	20	10	10	180	66.2	72.9	51.9	12.0	9
		S2	20	20	10	10	180	63.4	24.5	22.5	7.4	9
	8	S3	20	20	10	10	30	11.1	52.2	44.9	14.0	9
		S4	20	20	10	10	30	12.8	59.0	65.6	12.3	9

tions of rate and magnitude that jointly determine those quantities. The results unequivocally support the latter alternative. Within each of the three series of conditions, the proportion of responses to a key was systematically related to the combinations of rate and magnitude used to determine the constant total quantities of food pellets obtained for responding on each key. Within each series, preference for an alternative decreased as the reinforcers associated with that alternative became larger and less frequent in comparison with the reinforcers associated with the other alternative. This relation is shown for each series separately in Figures 1 to 3.

Figure 1 displays data from individual subjects under the eight conditions of Series 1. This figure, plotted in logarithmic coordinates, shows how responding on one key relative to responding on the other key depended on the frequency and size of the reinforcers on one key relative to those on the other key. The response ratios (left-key responses divided by right-key responses) are medians from the last three sessions of the conditions. In each condition, three times as many pellets were obtained on the left key as on the right key (300 pellets per session *versus* 100 pellets per session). If responses were distributed in the same ratio as the total quantities of reinforcer associated with the two keys, the points in Figure 1 would fall along the dashed straight line of zero slope. Instead, the ratio of responses on the two keys is inversely related to the ratio of pellets per reinforcement. In the most extreme instance, when the number of pellets per reinforcement was 15 times greater on the left than on the right, pigeons pecked nearly equally often on the two keys despite the fact that the left key provided three times as many pellets during the course of each session.

Figure 2 shows a similar relation for the conditions of Series 2, in which 350 pellets were obtained on the left key and 50 on the right key during each session. Again, the ratio of responses on the two keys decreased as the reinforcers on one key became larger and less frequent in relation to the reinforcers on the other key. Under the most extreme condition, when reinforcers on the 350-pellet key were 12.5 times as large as those on the 50-pellet key, pigeons responded less than twice as often on the 350-pellet key as on the 50-pellet key,

though matching to relative total amounts of reinforcer would predict a response ratio of 7 to 1.

Figure 3 displays data from Series 3 in the same fashion and again reveals an inverse relation between response ratios and ratios of pellets per reinforcement on the two keys. Although both keys provided 200 pellets per session, the proportion of responses to a key varied in an orderly fashion as reinforcer magnitude (and rate) on one key varied relative to reinforcer magnitude (and rate) on the other key.

The majority of conditions in Series 1 to 3 involved comparisons in which the two keys differed with respect to both reinforcer magnitude and reinforcer rate. Within each series, however, were experimental conditions in which reinforcer magnitude was equal on the two keys while reinforcer frequency was unequal, and other conditions in which the two keys differed in reinforcer magnitude but not in reinforcer frequency (see Table 1). Data from conditions in which reinforcers were of equal magnitude on the two keys are brought together in Figure 4, which displays the ratio

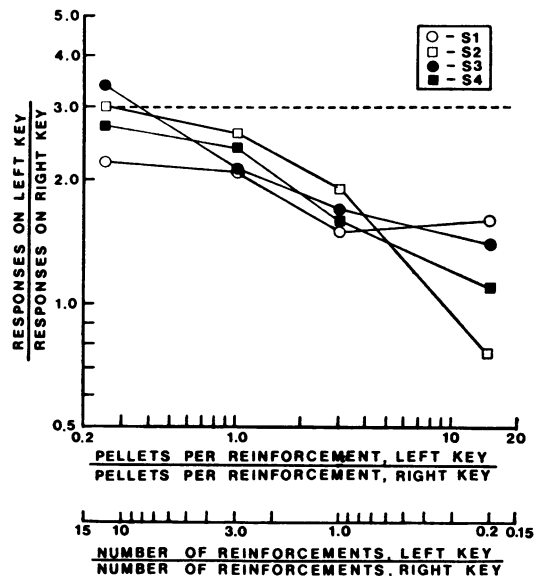


Fig. 1. For Series 1, the ratio of responses on the left key to responses on the right key plotted as a function of the ratio of pellets per reinforcement on the left key to pellets per reinforcement on the right key (upper abscissa) and the ratio of reinforcements on the left key to reinforcements on the right key (lower abscissa). The total number of pellets delivered for pecking the left key was three times the total number delivered for pecking the right key.

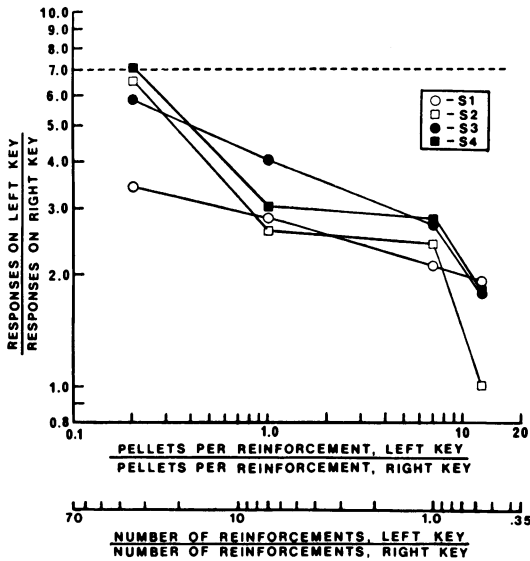


Fig. 2. For Series 2, the ratio of responses on the left key to responses on the right key plotted as a function of the ratio of pellets per reinforcement on the left key to pellets per reinforcement on the right key (upper abscissa) and the ratio of reinforcements on the left key to reinforcements on the right key (lower abscissa). The total number of pellets delivered for pecking the left key was seven times the total number delivered for pecking the right key.

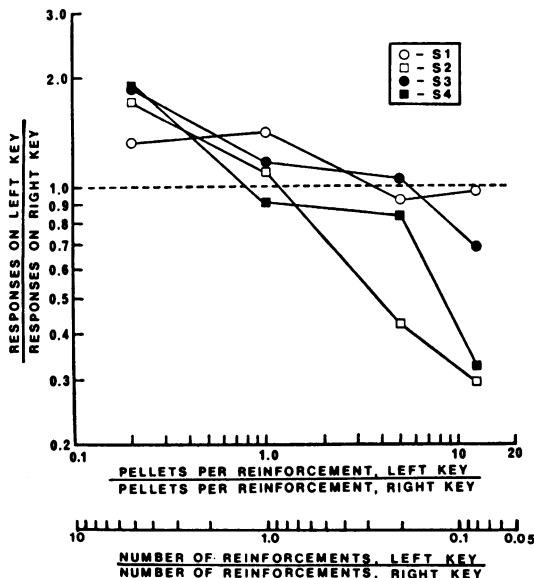


Fig. 3. For Series 3, the ratio of responses on the left key to responses on the right key plotted as a function of the ratio of pellets per reinforcement on the left key to pellets per reinforcement on the right key (upper abscissa) and the ratio of reinforcements on the left key to reinforcements on the right key (lower abscissa). Equal total numbers of pellets were delivered on the two keys.

of response rates on the two keys as a function of the ratio of reinforcement rates. If responses were distributed across the keys in the same proportion as reinforcements, points would fall along the dashed diagonal line in the figure. Instead, the response ratio increases less steeply than the reinforcement ratio, so that, except when reinforcement rates are equal on the two keys, the proportion of responses to a key is less than would be predicted on the basis of matching to relative reinforcement rates. It should be noted that while the number of pellets per reinforcement was equal on the two keys in each condition represented in Figure 4, this number differed from one set of conditions to the next, as shown in Table 1 (see Conditions 3 and 4 of Series 1; 7 and 8 of Series 2, and 7 and 8 of Series 3).

Series 1 to 3 also included conditions in which rates of reinforcement were equal on the two keys while the number of pellets per reinforcement differed. Figure 5 shows the ratio of response rates on the two keys as a function of the ratio of pellets per reinforcement on the two keys for these conditions (Conditions 1 and 2 of Series 1; 5 and 6 of Series 2; 7 and 8 of Series 3). The dashed

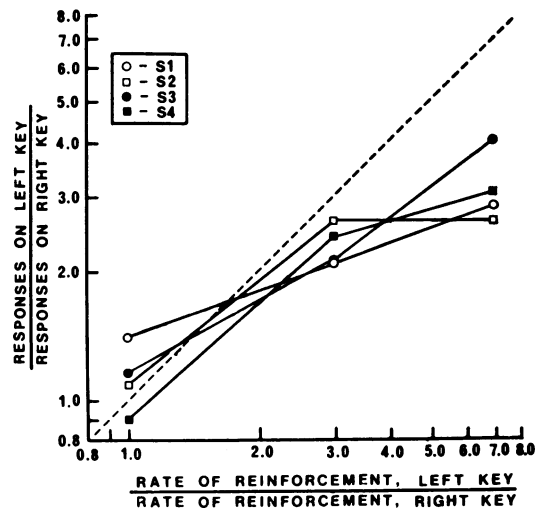


Fig. 4. The ratio of responses on the left key to responses on the right key plotted as a function of the ratio of reinforcement rate on the left key to reinforcement rate on the right key. In each condition shown, the number of pellets per reinforcement on one key equalled the number of pellets per reinforcement on the other key. The dashed line shows where points would fall if responses were distributed in the same proportion as reinforcements.

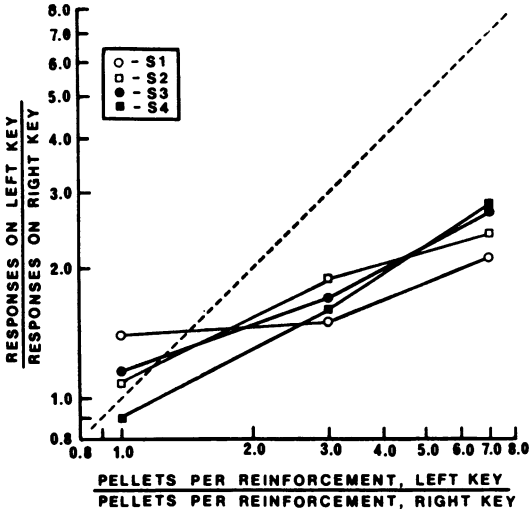


Fig. 5. The ratio of responses on the left key to responses on the right key plotted as a function of the ratio of pellets per reinforcement on the left key to pellets per reinforcement on the right key. Reinforcement rate on one key equalled reinforcement rate on the other key in each condition represented here. The dashed line shows where points would fall if responses were distributed in the same proportion as reinforcer magnitudes.

diagonal line shows where points would fall if the ratio of response equalled the ratio of reinforcer magnitudes. This equality was not obtained except when both reinforcer magnitudes and rates were equal on the two keys. For the remaining conditions, the degree of preference for a key was clearly less extreme than would be predicted on the basis of matching to relative magnitudes of reinforcement. It should be noted that reinforcement rates, while equal on the two keys for each condition of Figure 5, differed in their absolute values from one set of conditions to the next. (Reinforcement rates are calculable from the information provided in Table 1.)

Figures 4 and 5 show that when the keys differed with respect to reinforcer rates (Figure 4) or reinforcer magnitudes (Figure 5), responses were distributed more equally on the two keys than would be predicted by matching to either relative reinforcer rates or relative reinforcer magnitudes. Comparison of the slopes of the functions in the two figures reveals, however, that response ratios more closely matched the ratios of reinforcer rates than the ratios of reinforcer magnitudes. This is manifested quantitatively in the multiple

linear regression equation that describes the ratio of responses on the two keys (R_L/R_R) as a joint function of the ratio of reinforcement rates (r_L/r_R) and reinforcement magnitudes (a_L/a_R). Based on all conditions in Series 1 to 3, and expressed in terms of the logarithmic transformations from which it was calculated, this equation is:

$$\ln \left(\frac{R_L}{R_R} \right) = 0.0914 + 0.5961 \ln \left(\frac{r_L}{r_R} \right) + 0.3413 \ln \left(\frac{a_L}{a_R} \right) \quad [\text{Eq. 1}].$$

Equation 1 may be transformed to yield the power function

$$\frac{R_L}{R_R} = 1.096 \left(\frac{r_L}{r_R} \right)^{0.596} \left(\frac{a_L}{a_R} \right)^{0.341} \quad [\text{Eq. 2}].$$

The greater degree of control exerted by reinforcer rates than by reinforcer magnitudes is evidenced by the greater magnitude of the exponent on the fraction (r_L/r_R) than on the fraction (a_L/a_R) in Equation 2. Perfect matching to relative reinforcer rate and reinforcer magnitude would be represented by exponents of 1.0 on both (r_L/r_R) and (a_L/a_R). It should be noted that the left-right symmetry inherent in the two-key nature of the experiment demands that the multiplier in Equation 2, whose actual value is 1.096, be equal to 1.0 in the ideal case. The observed deviation reveals a slight key bias in favor of the left key.

Todorov (1973) also found it useful to express the ratio of response rates in his experiment as a power function of the ratio of reinforcer rates and reinforcer magnitudes (in this case, durations). In agreement with the present results, Todorov found that reinforcer rates exerted greater control over response rates than did reinforcer magnitudes. By way of comparison with Equation 2, exponents on the fraction (r_1/r_2) ranged from 0.5 to 1.2 in the Todorov study, depending on the subject, while the exponents on the ratio of reinforcement durations, (d_1/d_2), ranged from 0.2 to 0.4.

One implication of Equation 2 is that choice depends on the ratio of reinforcement rates (r_L/r_R) rather than on the absolute rates (r_L and r_R) *per se*. As may be seen in each of Figures 1 to 3, a given value of (r_L/r_R) produced about the same response ratio (R_L/R_R) for Subjects S1 and S2 as for Subjects S3 and

S4, although, throughout the experiment, r_L and r_R were about six times greater for S3 and S4 than for S1 and S2. A parallel implication of Equation 2, that choice depends on the ratio of reinforcer magnitudes (a_L/a_R) rather than on the absolute magnitudes (a_L and a_R), remains untested in the present study.

Absolute rates of responding to each key are shown in Table 1. The overall response rate ($R_L + R_R$) for each subject generally varied little across conditions, so that manipulations that produced changes in response rate on one key concomitantly produced opposing changes in responding on the other key (behavioral contrast). The manner in which responding on one key was affected by the scheduling of reinforcers on the other key is revealed in conditions that shared the same reinforcement parameters on one key but employed differing parameters on the other key (e.g., Conditions 1 and 3 of Series 1). Responding on the constant key was less when the reinforcer associated with the other key was distributed in small, frequent amounts than when it was distributed in larger, less frequent amounts. Likewise, responding on the other, variable, key was greater when that key provided small, frequent reinforcers than when it provided larger, less frequent reinforcers.

DISCUSSION

The present results show that the distribution of responses across a pair of concurrent alternatives depends on how the total quantity of reinforcer associated with each alternative is temporally apportioned. Responding on a key was maintained at a higher rate when its allotted quantity of reinforcer was delivered in frequent small amounts than when it was delivered in less frequent larger amounts. This finding is incompatible with the notion that reinforcer rate and reinforcer magnitude are functionally equivalent and that choice may be predicted from their product, a variable that expresses the average temporal density of reinforcer delivery associated with an alternative. Instead, reinforcer rate was found to exert greater control over the proportion of responses to an alternative than did reinforcer magnitude. When reinforcer rate and reinforcer magnitude were varied inversely so that their product was constant, responding to that alternative did not remain constant but

shifted in the direction of the change in reinforcer rate.

The ratio of responses to the two keys did not match the ratio of reinforcement rates when reinforcer magnitudes were equal, nor did it match the ratio of reinforcer magnitudes when reinforcer rates were equal (see Figures 4 and 5). The former observation is perhaps surprising in view of the large number of studies that have reported matching of relative response rates to relative reinforcement rates under concurrent scheduling (Herrnstein, 1970). Except when reinforcer rates (as well as magnitudes) were the same on both keys, responses were distributed more equally across the keys than would be predicted from the matching relation reported by Herrnstein (1961) and several subsequent investigators. One possibility is that the failure to observe close matching to relative reinforcement rates in the present experiment is a consequence of scheduling all reinforcements by single VI schedules instead of by pairs of independent VI schedules. As pointed out by Fantino *et al.* (1972), use of a single VI schedule to arrange reinforcements on two keys increases the penalty for failing to change over frequently to the nonpreferred key, and hence increases the penalty for distributing responses unequally across the two keys. The increased penalty arises from the fact that failure to produce a reinforcement as soon as it becomes available on one key (because of a period of exclusive responding to the other key) delays not only receipt of the presently scheduled reinforcer but all subsequently scheduled reinforcers as well. When independent VI schedules are used, subsequent reinforcements are less likely to be delayed as a consequence of a period of exclusive responding on one key. Despite these considerations, there is no present evidence that the single-VI two-key procedure detectably alters the choice function, and several investigators who have employed this or similar procedural variations have in fact observed matching of relative response rates to relative reinforcement rates (Herbert, 1970; Shimp, 1971; Stubbs and Pliskoff, 1969).

The mismatch between the ratio of response rates and the ratio of reinforcer magnitudes (Figure 5) was even greater than the mismatch between the ratio of response rates and the ratio of reinforcer rates (Figure 4). When re-

inforcers of unequal magnitude were scheduled at the same rate on both keys, the degree to which responding predominated on the more favorable key was considerably less than would be expected from the ratio of reinforcer magnitudes. Such absence of matching to relative reinforcer magnitudes is not without precedent. Although Catania (1963b) reported data in which relative response rates in pigeons matched relative durations of access to grain, the range of reinforcement durations employed was quite small and no data were reported regarding the obtained numbers of reinforcements on each key. Walker *et al.* (1970), using rats as subjects, varied relative duration of access to sucrose solution and found only poor matching of relative response rates to relative reinforcement durations. As in the present study, the degree of preference for an alternative was less extreme than would be predicted on the basis of relative reinforcer magnitude. Walker *et al.* suggested that the lack of matching might have been due to the relatively brief experience of their subjects with each pair of reinforcement durations, but this explanation does not readily account for the similar results of the present experiment. Although not specifically pointed out by the authors, similar deviations from matching are also evident in the results of a subsequent investigation by Walker and Hurwitz (1971). In this case, relative reinforcement durations were varied while relative rates of reinforcement were kept equal by means of the single-VI technique used in the present experiment. Clear deviations from matching were also found by Fantino *et al.* (1972) in an experiment involving concurrent alternatives whose reinforcement durations were unequal but remained fixed in value, and whose reinforcement rates were equal but assumed different values during the experiment. Relative response rates on the two keys differed less than did relative reinforcement durations both in conditions involving pairs of independent VI schedules and in the single condition that employed a single-VI two-key procedure.

In conjunction with the typical finding of matching when concurrent alternatives differ only in reinforcement rates, such results suggest that differences in reinforcement durations have a less potent effect on choice than do differences in reinforcement rates. This conclu-

sion finds additional support from Todorov (1973) who found that the proportion of choice responses was not accurately described by the relative total access to food, a measure that weights reinforcement duration and rate equally. In order to describe choice, Todorov found that the relative value of an alternative had to be adjusted to give greater weight to reinforcement rate than to reinforcement duration. The present results confirm the notion that reinforcement rates are relatively more potent than reinforcer magnitudes in determining choice between concurrent alternatives.

The present investigation found that a given quantity of reinforcer maintained a greater absolute and relative rate of responding on a key when it was delivered in frequent small amounts than when it was delivered in less frequent larger amounts. While it is not yet clear how best to account theoretically for this finding, one possibility might be formulated in terms of the diminished effectiveness of delayed reinforcement. When several food pellets are consumed serially during a reinforcement cycle, the last pellets ingested are temporally more distant from the response that produced them than are the first pellets ingested, and they may therefore be less effective in reinforcing that response. The first few pellets consumed within a reinforcement period would consequently provide a disproportionately large share of the total reinforcing effect afforded by the pellets consumed during that period. It follows that when two reinforcers differ in amount, the relative reinforcing effect of the larger would be less than would be expected on the basis of matching to relative amounts. In other words, the average reinforcing strength of each pellet in a large reinforcer may be less than in a small reinforcer because of the greater average temporal separation between ingestion of the pellets and the response that produced their delivery. In a two-choice situation involving reinforcers of unequal magnitude, preference for the larger reinforcer would therefore be less than one would expect on the basis of relative reinforcer magnitude alone, a prediction consistent with the present results.

There is a sense in which "reinforcer magnitude" is ambiguous. In current usage the term might legitimately refer to the duration of a reinforcer's accessibility, to the duration

of the consummatory behavior itself, to the volume or weight of the reinforcer, or even in some cases to the intensity of the reinforcer. For many types of reinforcers, these properties are nonetheless independently manipulable, and the manner in which concurrent performance is related to each dimension separately has not yet been ascertained. Such uncertainties aside, the present results make it clear that a given quantity of food maintains more behavior when it is delivered in small frequent portions than when it is delivered in large infrequent portions.

REFERENCES

- Brownstein, A. J. Concurrent schedules of response-independent reinforcement: duration of a reinforcing stimulus. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 211-214.
- Catania, A. C. Concurrent performances: reinforcement interaction and response independence. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 253-263. (a)
- Catania, A. C. Concurrent performances: a baseline for the study of reinforcement magnitude. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 299-300. (b)
- Catania, A. C. Concurrent operants. In W. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 213-270.
- Fantino, E., Squires, N., Delbrück, N., and Peterson, C. Choice behavior and the accessibility of the reinforcer. *Journal of the Experimental Analysis of Behavior*, 1972, 18, 35-43.
- Fleshler, M. and Hoffman, H. S. A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 529-530.
- Herbert, E. Two-key concurrent responding: response-reinforcement dependencies and blackouts. *Journal of the Experimental Analysis of Behavior*, 1970, 14, 61-70.
- Herrnstein, R. J. Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1961, 4, 267-272.
- Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, 13, 243-266.
- Rachlin, H. On the tautology of the matching law. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 249-251.
- Rachlin, H. and Baum, W. Response rate as a function of amount of reinforcement for a signalled concurrent response. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 11-16.
- Shimp, C. Matching in a concurrent FI FI schedule. *Psychonomic Science*, 1971, 22(1), 27-28.
- Stubbs, D. A. and Pliskoff, S. S. Concurrent responding with fixed relative rate of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 887-895.
- Todorov, J. C. Interaction of frequency and magnitude of reinforcement on concurrent performances. *Journal of the Experimental Analysis of Behavior*, 1973, 19, 451-458.
- Walker, S. F. and Hurwitz, H. M. B. Effects of reinforcer duration on concurrent response rates. *Psychonomic Science*, 1971, 22(1), 45-47.
- Walker, S. F., Schnelle, J., and Hurwitz, H. M. B. Rates of concurrent responses and reinforcer duration. *Psychonomic Science*, 1970, 21(3), 173-175.

Received 19 June 1972.

(Final Acceptance 19 June 1973.)